

Validation and Research Utilization of the NRL Regional Model for the U.S. West Coast

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LONG-TERM GOALS

Our long-term goal is to understand the spatially and temporally varying circulation in the California Current System. One aspect of the circulation is a quantitative description of the spatial and temporal variability of currents and water properties, including the time-varying mean fields and their higher order statistics. Another aspect is the quantification of the momentum, vorticity and heat balances that govern that variability.

OBJECTIVES

In this project, we are examining output from the regional numerical circulation model in use by the U.S. Navy at NRL, as applied to the circulation of the California Current.

Our specific objectives are:

- (1) To determine how well the regional nested NRL model reproduces the features and statistical fields as observed by satellites and field surveys (the seasonal development of 2-D spatial structure of surface velocity and eddy statistics, the seasonal development of the 3-D circulation, Lagrangian eddy statistics, etc.).
- (2) To use the model, in combination with the satellite and field data, to understand the processes that control transports in the large-scale eastern boundary current and the more detailed circulation over the shelf and slope; and
- (3) To develop the methodology for nesting high-resolution models of circulation over the west coast continental shelf and slope within the Navy regional model, to test the shelf models by comparison with observations, and to use the nested models to study the dynamics of shelf circulation processes.

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APPROACH

Navy modelers at NRL are developing and using a regional, coastal ocean circulation model with $1/12^\circ$ grid spacing that can be implemented in any part of the global ocean, nested within the Navy's global ocean circulation model. They are presently testing the regional model in the California Current System (CCS) along the U.S. west coast from 30°N — 50°N , using wind forcing from the U.S. Navy atmospheric model from July 1993 through 1997. This model (and its successors) will be used over the next five years in the CCS region under an internal NRL ARI with John Kindle as PI, including ecosystem and optical submodels.

Our general approach is to evaluate the realism of the NRL regional model by comparing statistical and dynamical analyses of the model output fields to identical analyses of satellite and in situ fields from the same region and period. We are also evaluating the ability of the regional model to provide boundary conditions for a nested, very high resolution coastal model.

The satellite data from this period consist primarily of altimeter surface height data and geostrophic velocities derived from the altimeter heights, for comparison to model surface height or pressure fields and model velocity statistics. Field data from these periods include surveys in the ONR EBC project off northern California in 1993 and surveys off Cape Blanco (43°N) during the NSF investigation of coastal jet separation in 1994 and 1995. Drifters released in these programs extend from 1993—1996. Moorings deployed in the EBC project collected two-years of data from 1993-1994.

The approach taken to investigate very high-resolution nested models is to use the NRL regional model of the U.S. West Coast to supply boundary values to a high-resolution limited area model (POM). The nested model domain surrounds Cape Mendocino (38.5°N to 42°N and offshore to 126°W) – a region of the coast that has not previously been modeled, but for which data is available (NCCCS, CTZ and STRATAFORM).

WORK COMPLETED

In preparation for the model analysis, statistical analyses of the altimeter and SST data have been completed and are in press (Strub and James, 1998). An initial evaluation of the in situ data has also been completed and is also in press (Shearman et al. 1998a). The model fields for statistical comparison to satellite data and in situ surveys are in the final stages of being generated at NRL for the 4.5 year period July 1993 – December 1997. Model “drifter” trajectories from the first three full years are finished and are being analyzed and compared to altimeter statistics at OSU. Model “hydrographic” fields from September 1993 are also being compared to the in situ data.

A nested model with three-kilometer grid spacing has been run for 20 days in July 1993. The model extends 385 kilometers alongshore and about 175 kilometers offshore and employs high-resolution bathymetry. Within the three-kilometer model, a second mass-conserving model has been nested with one-kilometer grid spacing, also with high-resolution bathymetry. This one-kilometer grid extends 200 km alongshore and about 150 km offshore and can interact through either “one-way” or “two-way” communication with the three-kilometer grid.

RESULTS

Satellite altimeter surface height and temperature fields show that an equatorward jet develops next to the coast in spring and summer. This jet moves offshore from spring to fall and contributes eddy kinetic energy to the deep ocean. In winter, a poleward inshore countercurrent is found in the 100 km next to the coast north of 33°N. Higher levels of EKE are confined to the region within 750 km of the coast, inshore of a more quiescent “eddy desert” found farther offshore. The dominant spatial scales of the eddies and meanders in the jet are 100-300 km. A sequence of snapshots from October 1992 to

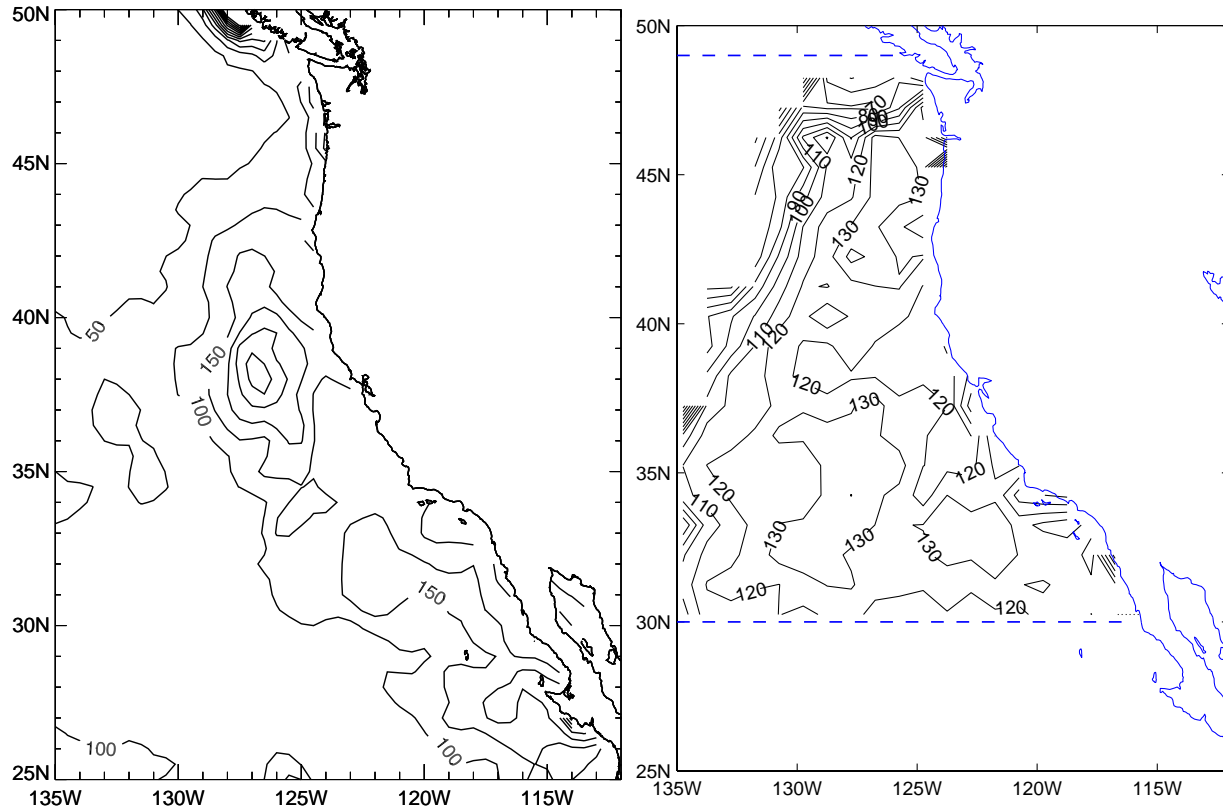


Figure 1. Contours of variance of crosstrack geostrophic velocities (approximating the EKE) from four years of TOPEX altimeter data (left), compared to contours of EKE estimated from three years of model “drifters”. Contour intervals are $50 \text{ cm}^2 \text{ s}^{-2}$ (left) and $20 \text{ cm}^2 \text{ s}^{-2}$ (right). Dashed lines denote the model boundaries.

October 1993 shows details of the evolving jet and eddy system over one complete annual cycle (Strub and James, 1998, and the web site given above) on scales of 50—2000 kilometers. Figure 1a (left) shows an estimate of the average cross-track variance in geostrophic surface velocities from the altimeter data (approximately equal to EKE, assuming isotropy), showing a primary maximum ($300 \text{ cm}^2 \text{ s}^{-2}$) off northern California. Figure 1b (right) a preliminary estimate of the EKE from binned model “drifter” data over a three-year period. Over 500 drifters are tracked at a given time, released every 6 months from a regular grid and re-released when they leave the domain or hit land (3×10^6 total drifter days). Maximum values of EKE in the model appear to be lower than in the altimeter data by a factor of two. Moreover, the model produces a local minimum near where the altimeter data show the overall maximum in EKE (38°N) and the model fails to reproduce the rapid decrease in EKE in the offshore region. More detailed comparisons of the seasonal behavior of EKE and other statistics will be completed in the last year of the project.

On a smaller scale, in situ observations from a high-resolution upper-ocean SeaSoar/ADCP survey of a strong cyclonic jet meander have been used to diagnose the associated three-dimensional circulation (Shearman et al. 1998a). SeaSoar data show a density front at a depth of 70-100 m with strong cyclonic curvature. The geostrophic velocity fields, referenced to the ADCP data at 200 m, show a surface-intensified jet (0.8-1.0 m/s) that follows the density front. Relative vorticities within the jet are large, ranging from $-0.8f$ to $+1.2f$. The SeaSoar density and ADCP velocity data are used to diagnose vertical velocity via the Q-vector form of the quasigeostrophic omega equation. The diagnosed vertical velocity field shows a maximum of 40-45 m/d and is characterized by horizontal length scales of 20-30 km. The dynamics of the gradient wind balance are important in mesoscale features with strong curvature. Higher-order diagnostics, that incorporate the gradient wind balance, of the three-dimensional circulation have been developed and applied (Shearman et al. 1998b). Higher-order horizontal velocities (the gradient wind) are subgeostrophic (supergeostrophic) in regions of cyclonic (anticyclonic) curvature. Higher-order estimates of vertical velocity are 30-40% less than the quasigeostrophic vertical velocity (Fig. 2). This reduction is consistent with the gradient wind balance, and is due to a reduction in the forcing of the omega equation through the geostrophic advection of ageostrophic relative vorticity. The NRL model output are being analyzed in a similar manner and compared to the EBC survey results, to determine how well the model reproduces the observed California Current mesoscale features.

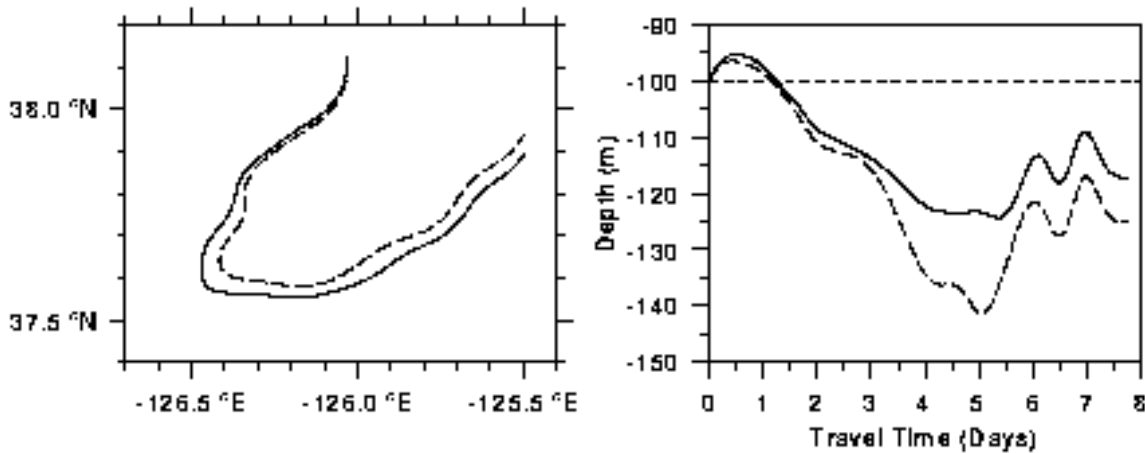


Figure 2. (left) At 100 m, horizontal water parcel trajectories computed from the geostrophic velocities (dashed line) and the higher-order gradient wind velocities (solid line); (right) net vertical displacement, computed by integrating the quasigeostrophic vertical velocity (dashed line) and higher-order vertical velocity (solid line) along the geostrophic trajectory shown at left. The displacement computed from the higher-order vertical velocity is less than the quasigeostrophic displacement, illustrating the importance of including higher-order dynamics.

Initial results have also been obtained with the nested models. Comparison of velocities from 250 meter depth (the level of the poleward undercurrent) in the three-kilometer nested simulation to those from the NRL regional “coarse-grid” model (Figure 3, below) reveals stronger eddies on a number of scales in the nested model. A tightened and strengthened cyclonic eddy to the southwest of Cape Mendocino in the nested model (42.4°N , 124.5°W) has similar dimensions and flow characteristics to a deep eddy observed during the NCCCS program, but is only weakly resolved in the coarse model. The nested-grid resolves a number of features not found on the coarse-grid and has more intense temperature and salinity fronts. More importantly, transport paths from the shelf to the deep ocean are different and appear more constrained by topography in the nested model.

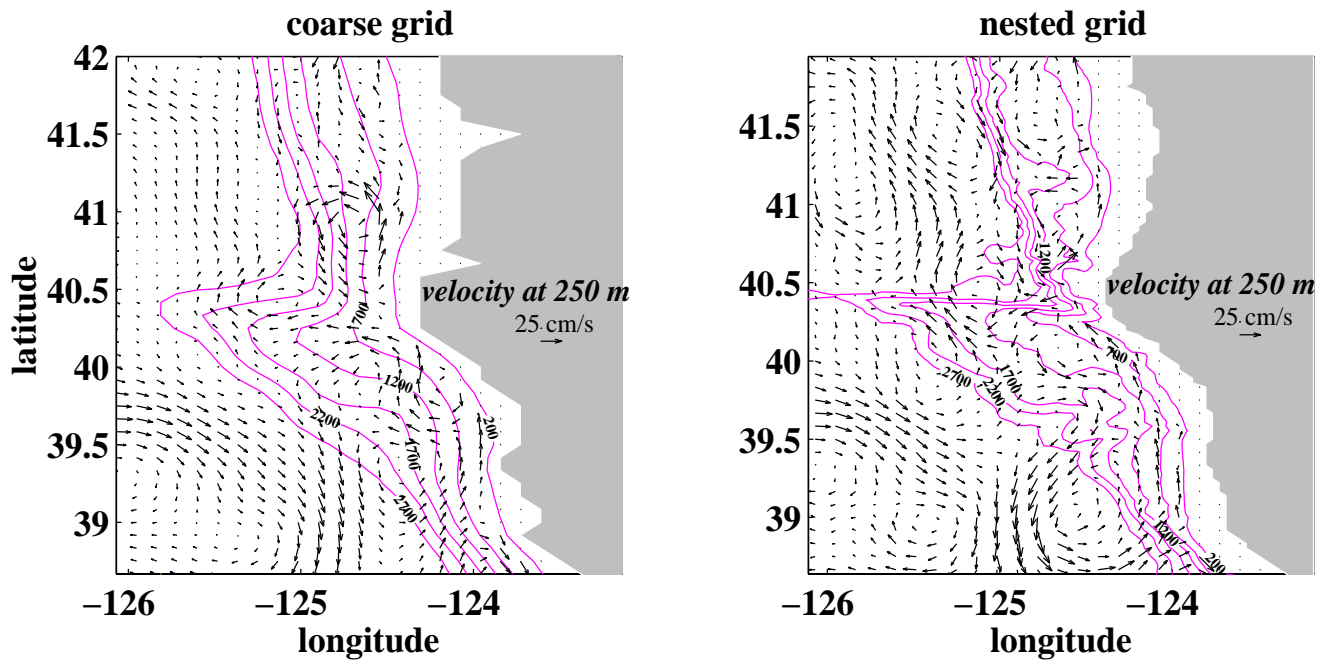


Figure 3. Velocities from the coarse NRL model (left) and three-kilometer nested grid (right) at 250 m in summer.

IMPACT/APPLICATIONS

The Navy is developing this relocatable regional model for global operational use. The same model is planned to be used as NOAA's operational coastal ocean forecast model off the west coast. Fields from the model will be used by the Coast Guard for search and rescue efforts, by fisheries managers, and many others, including academic researchers. Given this level of use for the model output fields, it is vital to quantify the errors in the model fields, so that model fields be better interpreted.

TRANSITIONS

As stated above, the model will be used operationally by many agencies and individuals. The results from our validation efforts will also become a part of that operational model deployment, in the form of estimates of model uncertainty.

RELATED PROJECTS

1. John Kindle and coworkers are using the NRL regional model as the basis for ecosystem models and optical models at NRL.
2. A similar model evaluation using altimeter data will be performed on the POCM (Semtner and Chervin) model in collaboration with B. Semtner and R. Tokmakian.
3. Results of this study will be communicated to those modeling and observing the California Current in the US GLOBEC North-East Pacific study. Strub and Barth are PI's on different projects in the GLOBEC project.
4. John Allen is conducting high resolution modeling of the shelf region in the northern California Current region (Oregon) within CoOP and NOPP projects, also in close collaboration with GLOBEC modelers.

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Strub, P.T., and C. James, 1998. Altimeter-derived variability of surface velocities in the California Current System: 2. Seasonal circulation and eddy statistics. *Deep Sea Res.* (in press).

PUBLICATIONS

Shearman, R.K., J.A. Barth, and P.M. Kosro, 1998. Diagnosis of the three-dimensional circulation associated with mesoscale motion in the California Current. *J. Phys. Oceanogr.* (in press).

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